THIS PAGE BLANK (USPTO)

09/720782
525 Rec'd PCT/PTO 27 DEC 2000

602985.1002

Priority paper
#3
P. Walker

UNITED STATES PATENT AND TRADEMARK OFFICE

Re: Application of: Robert Charles SKERRITT, et al.

Serial No.: Not yet known

Filed: Herewith

For: RESIDUAL CURRENT DETECTION DEVICE

LETTER RE PRIORITY

Assistant Commissioner for Patents
Washington, DC 20231-9998

December 27, 2000

Dear Sir:

Applicant hereby claims the priority of British Patent Application No. 9813982.7 filed June 30, 1998 through International Patent Application No. PCT/GB99/02060 filed June 30, 1999.

Respectfully submitted,

J. David Dainow
Reg. No. 22,959

Steinberg & Raskin, P.C.
1140 Avenue of the Americas, 15th Floor
New York, NY 10036-5803
Telephone: (212) 768-3800
Facsimile: (212) 382-2124
E-mail: sr@steinbergraskin.com

F:\H\602985\1002\PROSEC\PRIO.WPD

PCT/GB99/02060

The Patent Office

INVESTOR IN PEOPLE

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

REC'D 28 JUL 1999
WIPO PCT

09/720782

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 16 JUL 1999

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
RECEIVED BY POST

The Patent Office

1/77

30JUN98 E371772-6 D00355
P01/7700 25.00 - 9813982.7

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

1.	Your reference	P036853PGB
2.	Patent application number *(The Patent Office will fill in this part)*	30 JUN 1998 **9813982.7**
3.	Full name, address, and postcode of the or of each applicant *(underline all surnames)*	MEM Limited, Turkey Shore, Holyhead, Anglesey, Gwynedd, LL65 2DH, England.
	Patents ADP number *(if you know it)*	7446766001
	If the applicant is a corporate body, give the country/state of its incorporation	England
4.	Title of the invention	RESIDUAL CURRENT DETECTION DEVICE
5.	Name of your agent *(if you have one)*	Marks & Clerk
	"Address for Service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Alpha Tower Suffolk Street Queensway Birmingham B1 1TT
	Patents ADP number *(if you know it)*	18002
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application give the number and filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	YES

Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document.

Continuation sheets of this form	
Description	6
Claim(s)	
Abstract	
Drawing(s)	2

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 29 JUNE 1998

12. Name and daytime telephone number of person to contact in the United Kingdom — Roger Prutton 0121 643 5881

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Residual Current Detection Device

This invention relates to a residual current correction device for use in a circuit breaker.

Conventionally, residual current correction is detected utilising a current transformer having primary windings through which, in the case of a single phase device, load current flows in opposite directions so that if the return current is different from the outwardly flowing current because of current leakage an output voltage signal is induced in a secondary winding of the transformer. In the case of a multi-phase device, primary windings of the transformer are connected in all of the phase lines and the neutral line. In normal situations, when there is no current leakage, the net current in the lines is zero so that no output voltage is zero.

Sophisticated materials have been developed for the core of the current transformer, which enable considerable accuracy to be obtained when the currents flowing in the primary windings are substantially sinusoidal. However, switch mode power supplies are often used for computers and other equipment and there is an increasing tendency for such equipment to cause dc offsets in the currents. Such developments have made detectors utilising current transformers less reliable and prone to false tripping or failure to detect a dc current leak.

This is a particular problem in the case of directly actuated electro-mechanical devices, where the current transformer secondary actually drives an actuator. The situation is not much improved, when by including an electronic detection and amplification means connected to the secondary winding, as there are still problems with high frequency transients and dc offsets. A very small dc current level can cause the core

to saturate thereby seriously impairing the ability of the detector to detect current leakage.

It is an object of the present invention to provide a residual current detection device in which the above mentioned problems are substantially overcome in a simple and efficacious manner.

In accordance with the invention there is provided a residual current detection device comprising a plurality of resistive shunts for connection in respective ones of a plurality of lines though which current can flow to and from a load, and detector means sensitive to the voltage developed across each of the shunts to detect any imbalance between the currents flowing though the shunts.

Preferably, the detector means comprises an analog to digital converter for each shunt and a processor for receiving the digital signals from the converters and determining whether a current imbalance exists.

Each shunt preferably takes the form of a composite strip having conductive portions at its ends and a resistive portion interconnecting the conductive portions. Such composite strips can be mass produced inexpensively to very high tolerances which makes them extremely suitable for this purpose.

The analog to digital converter for each shunt may include a delta-sigma modulator, which generates a high frequency single digital data stream which is converted by decimation filtering to a multibit digital data stream at a lower frequency.

The analog to digital converter for each shunt is preferably connected to

the processor through an isolation barrier so that the converter can float at the voltage level of the shunt which it serves. The decimation filtering may be effected entirely in the converter, entirely in the processor or split between the converter and the processor.

In the accompanying drawings:

Figure 1 is a diagrammatic perspective view of an example of the invention as applied to a single phase device and

Figure 2 is a block diagram of an another example of the invention as applied to a three phase device.

In the device shown in Figure 1, a substrate 10 supports two composite conductor strips 11, 12. Each of these includes end portions 13 of copper and an intermediate portion 14 of a resistive material such as manganin. The strips are formed by slicing up a sandwich formed by electron beam welding the copper portions to opposite sides of the manganin portion. The shunts formed by the resistive portions manufactured by this method can have a nominal resistance of 0.2mΩ to a tolerance of less than 5%. If the two shunts 14 used on one device are pressed from adjacent portions of the sandwich stock, they are matched to within 2%. Calibration of the shunts built into a unit at two different temperatures can virtually eliminate shunt errors.

In the example shown in Figure 1, there is a separate signal pre-processing ASIC 15 mounted on each of the shunts 14 and connected to the copper end portions 13 of the associated conductor strips. The two ASICs 15 are connected to via an isolation transformer array 16 to a main processor 17. The ASICs 15 operate to convert the two voltages across the shunts into a

digital signal stream which is communicated to the processor 17 via the isolation transformer array. The main processor is programmed to provide a drive signal to a trip actuator 18.

Figure 2 shows in rather more electrical detail a three phase device. In this case there are four shunts 14, one in each phase line and a fourth in the neutral line. The ASICs 15 of Figure 1 are shown as four separate blocks 20, 21, 22, and 23, and there is a power supply unit 24 which draws power from the phase lines on the mains side of the shunts 14 and provides controlled voltages to the processor 17. Power is supplied to the four blocks 20 to 23 via isolation barriers 25 which make up the array 16. Each block of the ASIC includes an analog to digital converter in the form of a delta-sigma modulator which provides a high frequency one bit digital data stream. A multiplexer may be included in each converter so that the converter can provide to the processor, through the respective isolation barrier, signals representing both current in the associated shunt and the voltage at one end of it. The processor uses these signals to monitor the current in each shunt and to operate the actuator 18 if an imbalance occurs.

It will be noted that the voltage sensing connections to the ASICs are made via resistor chains connected between each phase line and the neutral. Each such resistor chain comprises an outer pair of precision resistors of relatively low ohmic value and an intermediate resistor of relatively high ohmic value. These resistor chains allow the RCD to be provided with an independent reference. If the neutral ADC is taken as the selected system reference, then the operating software of the main processor can use the multiple signals derived from the several resistor chains to calibrate each phase against the neutral reference.

The CPU is programmed to carry out the necessary calculations to determine the existence of an imbalance and can determine the true RMS value of the residual current, which conventional devices fail to do correctly particularly in the case of non-sinusoidal current waveforms. The CPU may be programmed to enable it to determine from the data it receives whether a particular event is, in fact, an unacceptable leakage more reliably than conventional devices. For example, the CPU can take into account the historic performance of the unit when setting the leakage current threshold and may ignore events which have a recognisable "signature". In this way improved tolerance to nuisance tripping can be obtained

Decimation filtering of the high frequency one bit data stream is required to reduce each data stream to a multi-bit digital signal at a predetermined sample frequency. By way of example, each current signal may be a 23-bit signal at a sample rate of 64 times the mains frequency, but lower resolution at lower sample rates can be employed when non-linear, rather than linear conversion is acceptable. The decimation filtering is typically a function of the processor, filtering of the four data streams being executed simultaneously so that sample values are derived for all four shunts simultaneously.

In alternative embodiments, one or more stages of the decimation filtration may be executed by hardware included within the ASIC. Multi-bit digital words are transmitted serially across the isolation barriers instead of a one-bit signal stream.

The arrangements described enable very accurate detection of current imbalance to be effected even in the presence of switching transients and DC offsets. The problems which arise from potential saturation of the

current transformer core are avoided completely.

Since the CPU receives actual line current and voltage data from each of the blocks 20 to 23, it can be programmed to perform other calculations, such as current limit and power consumption. Thus an RCD device constructed as described above can also provide the functions of a conventional circuit breaker and/or those of a power consumption meter without any additional sensing or analog-to-digital components being required.

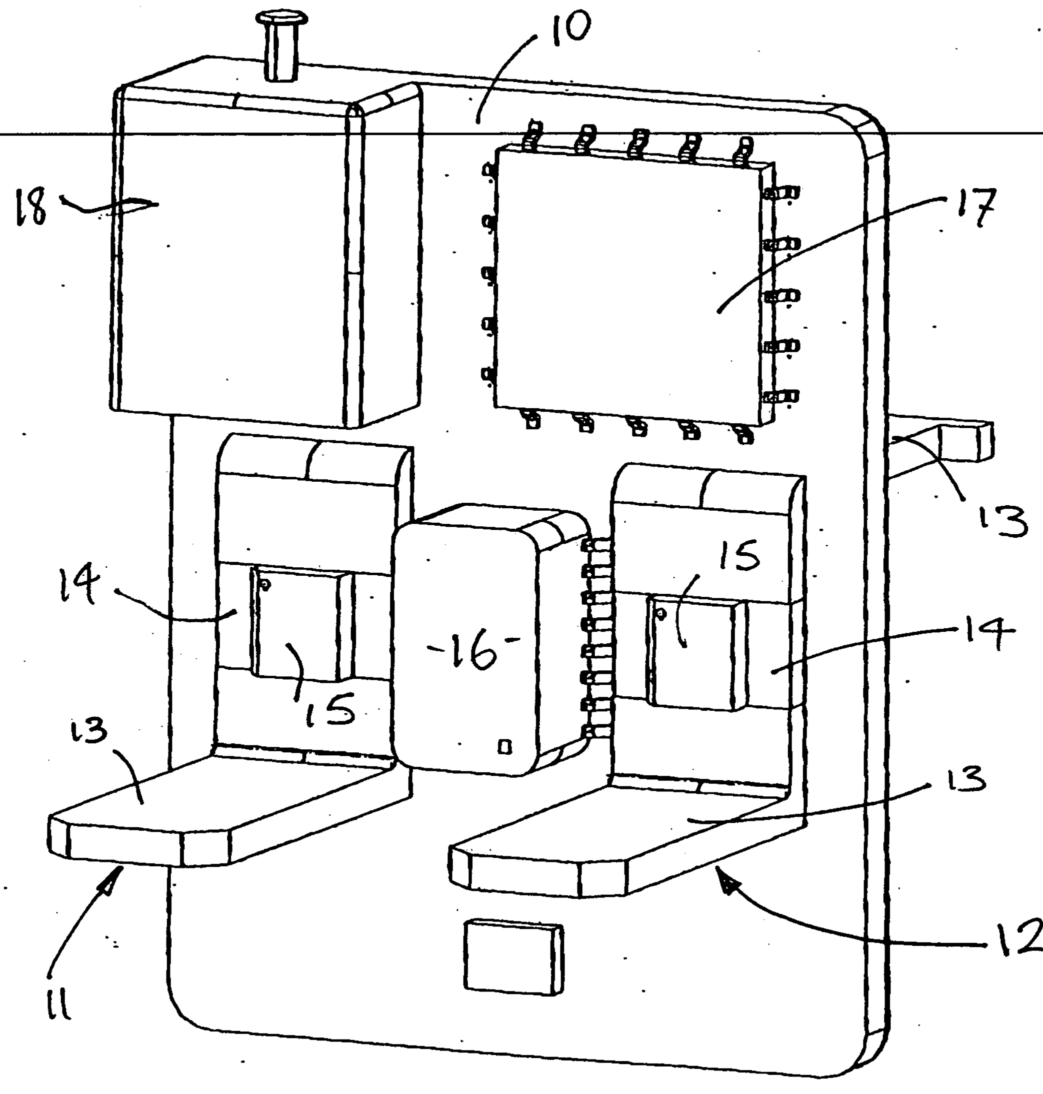
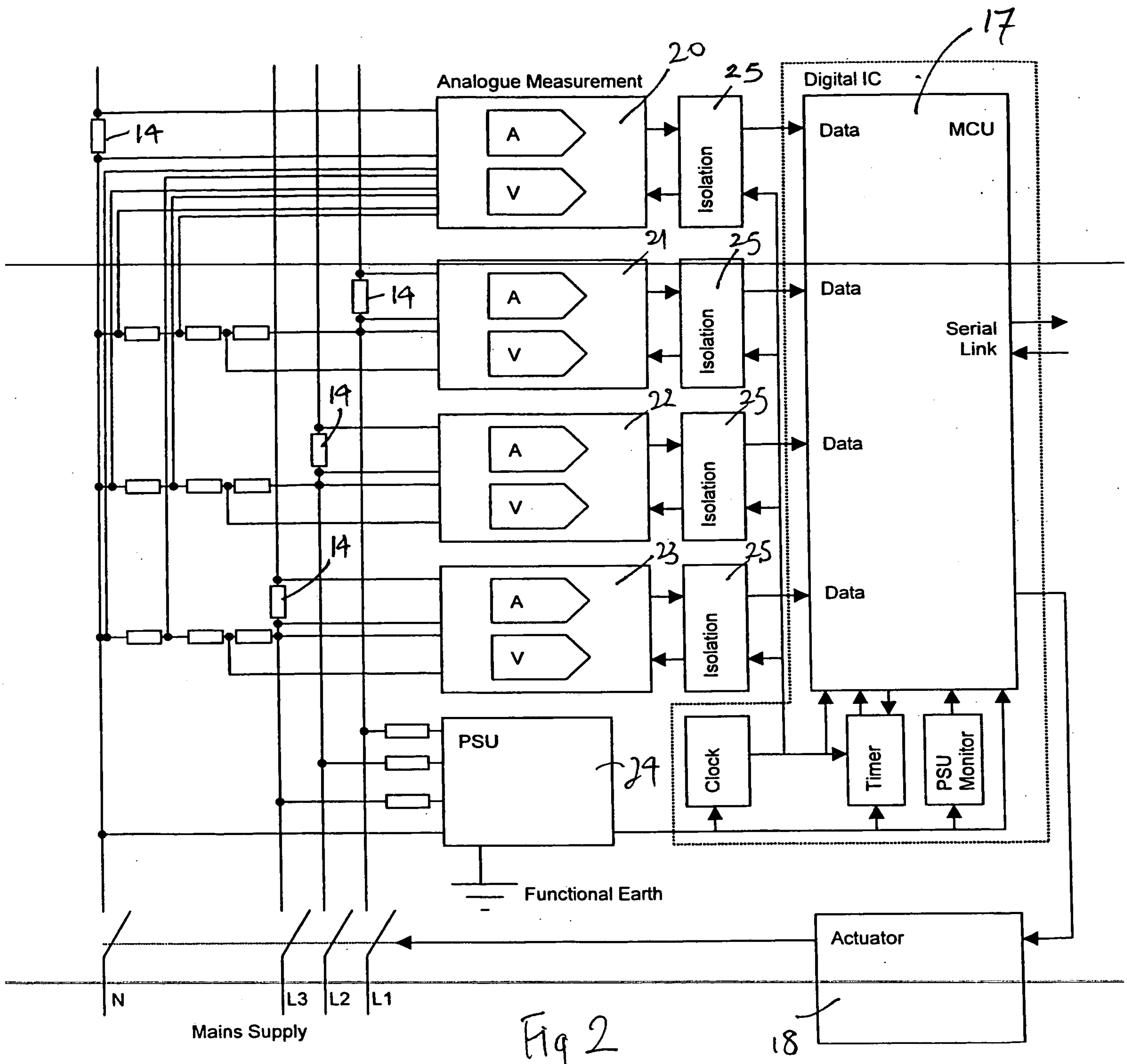


Fig 1



17
20
25
Analogue Measurement
Digital IC
14
A
V
Isolation
Data
MCU
21
25
14
Data
Serial
Link
14
22
25
Data
14
23
25
Data
PSU
24
Clock
Timer
PSU
Monitor
Functional Earth
Actuator
N
L3
L2
L1
Mains Supply
18

Fig 2

Again, the detector must provide an output at a particular point in the envelope, for example at peaks, and again, jitter needs to be minimised.

The disparities computed may need integrated across time, across channels, and across the different detectors, prior to being used. In addition, IIDs may be computed for each channel, and this together with the integrated disparity measure may be used to produce a direction estimate for each channel. This may be displayed to the user as a map, in a form such as that in figure 3.

The display shows the azimuthal direction of the different incoming sounds (though not whether the sound is ahead of or behind the user). This, on its own could be used to draw attention to features of the auditory environment. It can be made much more useful to the hearing impaired by permitting them to interact with it to select the information to be presented to them by the hearing aid itself. How this is best achieved will depend on factors which will vary from user to user, such as whether they are willing to use their hands to interact with the system, or would prefer to interact only by turning their heads.

Two modes of sound selection are embodied. In the preferred embodiment, the user turns to face the (known) source of the sounds in which they are interested. The sounds to be selected are then those with low ITD and IID. In another embodiment, a map of the incoming sounds is produced and displayed, and the user selects the sounds to be presented.

Figure 3 shows one possible form of display. The display takes the form of a semicircle, because the system cannot distinguish between sounds from in front and behind. The user interacts with the display, selecting a particular direction (e.g. by touching the display) from which they wish to be presented with sounds. The display returns the angle selected, and this is then processed.

The information to be presented to the user may be presented monaurally or binaurally. The following discussion, illustrated in figures 4 and 5, assumes monaural presentation. The result of the user's interaction with the interactive display is an angle, θ between $-\pi/2$ and $+\pi/2$ or 0, if the user requests only those sources directly ahead. This angle is used to

compute the expected IID and ITD for signals from that direction. The ITD estimate is compared with the ITD computed by the three disparity calculators in each channel.For each channel, these three values are used to compute an estimate of that channels contribution produced by sources from that direction. For each ear, these estimates are normalised (to a length of 1), and this vector (ControlLMix for the left ear, and ControlRMix for the right ear) used to control a mixer. This produces two multichannel outputs, OutDataL and OutDataR.

These are then mixed together in a ratio determined by the expected IID. This takes account of the fact that for sources with $|\theta| > \pi/4$, one ear will receive a much stronger signal than the other. The resultant output, OutData, is a multichannel signal, suitable for visual display. For auditory presentation, the signals in the different channels need to be added together in a way which reflects the user's hearing deficit.

Exactly how the selected sounds are presented to the user depends very much on the sensory faculties of the user. If there is sufficient residual hearing, then selective amplification may be most suitable: if the residual hearing is restricted to particular frequency bands, then resynthesis may be more appropriate. It may also be possible to mix these two techniques. Alternatively, presentation may use the visual modality.

The selected sound, produced as outlined in figures 4 and 5 can have some channels selectively amplified to make up for the hearing deficit. The resulting sound may be presented (a) monaurally, if there is only sufficient residual hearing in one ear, or (b) binaurally if there is sufficient residual hearing in both ears. In this case, we would present the data from OutDataL to the left ear, and from OutDataR to the right ear.

Additionally, we can still use the ControlLRMix signal to alter the gain on the signals from the two ears.

Where the residual hearing is restricted to a small part of the auditory spectrum, or, indeed, where the presentation takes place through an implant, it may be more appropriate to resynthesize the sound to take advantage of whatever hearing is available. Again, the signal we start from is the OutData signal.

Where there is little or no residual hearing, we would present the information from the sound in one particular direction visually. This would use a colour display to present information about how the power of the sound was distributed over the spectrum.

One possibility (which does not use the interactive display, but displays all the incoming sound) would be to choose the colour to match the ITD, and to make the intensity reflect the strength of the signal.

Alternatively, one could use the interactive display to select the direction of the sources to be presented, and use the colour of the display to show the presence and pitch of amplitude modulation, keeping white for non-amplitude modulated areas of the spectrum, and again using the intensity to show the signal strength. This would use information present in figure 5, but not used in the auditory presentation.

The interactive system needs to work under strict real-time constraints. In addition, the system needs to be light, and wearable, and to run with a low power consumption. Most current sophisticated hearing aids use digital signal processing (DSP) techniques. DSP circuits are generally organised as reconfigurable fast parallel multipliers and adders. This is highly appropriate for convolution computation, and is highly effective for e.g. digital filtering. Non-linear operations are also possible on such chips. However, although DSP technology is very fast, it is not inherently parallel, and we wish to process multiple channels simultaneously. In addition, there is a speed/power tradeoff.

An alternative technology is subthreshold analog VLSI (C. Mead . Analog VLSI and Neural Systems . Addison-Wesley, 1989). This technology works at extremely low power levels, and this allows highly parallel circuits which operate at low power to be designed. In addition, the exponential characteristic of one of the basic components, the transconductance amplifier, mirrors the characteristics of the biological system rather better than either digital on/off switches, or more linear analogue devices.

Sound detection may be through microphones. Alternatively, direct silicon transducers for pressure waves may be used. In the preferred embodiment there are two microphones, mounted on the user's ears (either behind the ear, or in the auditory canal). The microphones

should be omnidirectional: we need to receive signals from all directions so we can estimate the directions of sound sources.

We describe here one possible neuromorphic implementation of some of the processing described above, though it is understood that this implementation is given by way of example only and is not intended to limit the scope of the invention. This processing takes place in stages. For the input from each ear, the first stage (after transduction) is cochlear filtering, and this is followed (in each bandpassed channel) by (in parallel) pitch phase detection, and envelope processing (i.e. amplitude modulation phase detection and onset detection). The results of all of this processing (for all channels, and for both ears) are used to generate ITD estimates for each feature type for each channel. This information is then used in determining what should be presented to the user, as described in figures 4 and 5.

The use of neuromorphic technology for real-time cochlear filtering goes back to R.F. Lyon and C. Mead. An analog electronic cochlea. IEEE Transactions on Acoustics, Speech and Signal Processing , 36(7):1119--1134, 1988) and has been extended by J. Lazzaro and C. Mead Silicon modeling of pitch perception Proceedings of the National Academy of Sciences of the United States, 86(23):9597--9601, 1989 , and W. Liu, A.G. Andreou, and Jr. M.H. Goldstein. Analog cochlear model for multiresolution speech analysis. In Advances in Neural Information Processing Systems 5, pages 666--673, 1993, and W. Liu, A.G. Andreou, and Jr. M.H. Goldstein. Voiced speech representation by an analog silicon model of the auditory periphery. IEEE Trans. Neural Networks, 3(3):477--487, 1993 , L. Watts Cochlear Mechanics: Analysis and Analog VLSI PhD thesis, California Institute of Technology, 1993 , and more recently by E. Fragniere, A. van Schaik, and E.A. Vittoz Design of an analogue VLSI model of an active cochlea Analog Integrated Circuits and Signal Processing , 12:19--35, 1997 . The advantages of the neuromorphic solution are that it is inherently real-time, and low power, unlike DSP implementations. It is not yet possible to achieve as high a quality factor (Q) or as many stages as achieved by the human cochlea, but the most recent techniques (A. van Schaik. Analogue VLSI Building Blocks for an Electronic Auditory Pathway. PhD thesis, Ecole Polytechnique Federale de Lausanne, 1997) can provide 104 stages using a second order low-pass filter cascade.

Pitch phase detection in animals relies on population coding by spiking neurons which are more likely to spike at a particular phase of the movement of the basilar membrane. Neuromorphic implementations of this are discussed in W. Liu, A.G. Andreou, and Jr. M.H. Goldstein Voiced speech representation by an analog silicon model of the auditory periphery IEEE Trans. Neural Networks, 3(3):477--487, 1993 and in techniques (A. van Schaik. Analogue VLSI Building Blocks for an Electronic Auditory Pathway. PhD thesis, Ecole Polytechnique Federale de Lausanne, 1997), where a version of Meddis's hair cell model (M.J. Hewitt and R. Meddis An evaluation of eight computer models of mammalian inner hair-cell function, Journal of the Acoustical Society of America, 90(2):904--917, 1991) is implemented. In both these cases, both the tendency to synchronize with the input signal below about 4Khz, and the rapid and short-term adaptation are modelled.

However, if the aim is simply to encode the phase of the signal emanating from each bandpass filter, then one possible technique would be rectification followed by peak detection, or alternatively, simple positive-going zero crossing detection. Either of these can be easily accomplished using neuromorphic techniques. In J. Lazzaro and C.A. Mead. A silicon model of auditory localization. Neural Computation, 1(1):47--57, 1989 a model of the barn owl's auditory localisation system is implemented neuromorphically using a detector sensitive to zero-crossings of the derivative of the half-wave rectified bandpass filter output.

Although it would be possible for a neuromorphic system to retain pitch-synchronous operation at high frequencies, source direction detection is difficult because of the short wavelength of these signals. Matching the peaks leads to ambiguity in the source direction. However, if the result of bandpassing the signal at high frequencies is that there is amplitude modulation at a lower frequency, then the difference in the phase of the modulation between the two detectors may be used. Neuromorphic detection of amplitude modulation (modelling stellate cells in the cochlear nucleus) is discussed in A. van Schaik Analogue VLSI Building Blocks for an Electronic Auditory Pathway PhD thesis, Ecole Polytechnique Federale de Lausanne, 1997 in the context of periodicity extraction. Although the same techniques could be used for ITD estimation, it is perhaps simpler to low-pass filter the pitch-synchronous phase detector, and generate a pulse on each peak (or on each positive-going zero-crossing).

Neuromorphic implementation of the onset detector may be achieved using a neuromorphic spiking neuron.

Since there are three independent techniques for ITD computation in each channel (although amplitude modulation would not be used below about 1Khz, and pitch synchrony would not be used above about 4Khz), we are liable to have both a number of estimates at different parts of the spectrum, and even a number of estimates at each part of the spectrum. There may be many sound sources at any one time, so that all these estimates may well be correct.

A mixture of subthreshold analogue, supra-threshold analogue and digital techniques may be applied to the production of the neuromorphic implementation of the control signal generation and of the mixers.

What is to be presented will be produced from the OutData signal (or OutDataL and OutDataR signals in the case of binaural presentation). Auditory presentation technology will preferably use remote generation of the signal, and transmission of the signal to the in-ear transducers by wireless technology. In addition, it may be necessary to adjust the spectral energy distribution and compress the signal to take best advantage of the residual hearing present. For visual presentation, some form of low power flat panel display (such as those used in colour portable computers) may be most appropriate.

Noting that the bandpass characteristic of current neuromorphic filters is not as sharp as we would like we may counterbalance this by (i) choosing only those channels for which the chosen ITD is most strongly represented and (ii) as well as selectively amplifying these channels, subtracting the content of channels in which the ITD chosen is under-represented.

It will be understood that the embodiments of the invention herein before described are given by way of example only and are not meant to limit the scope thereof in any way.

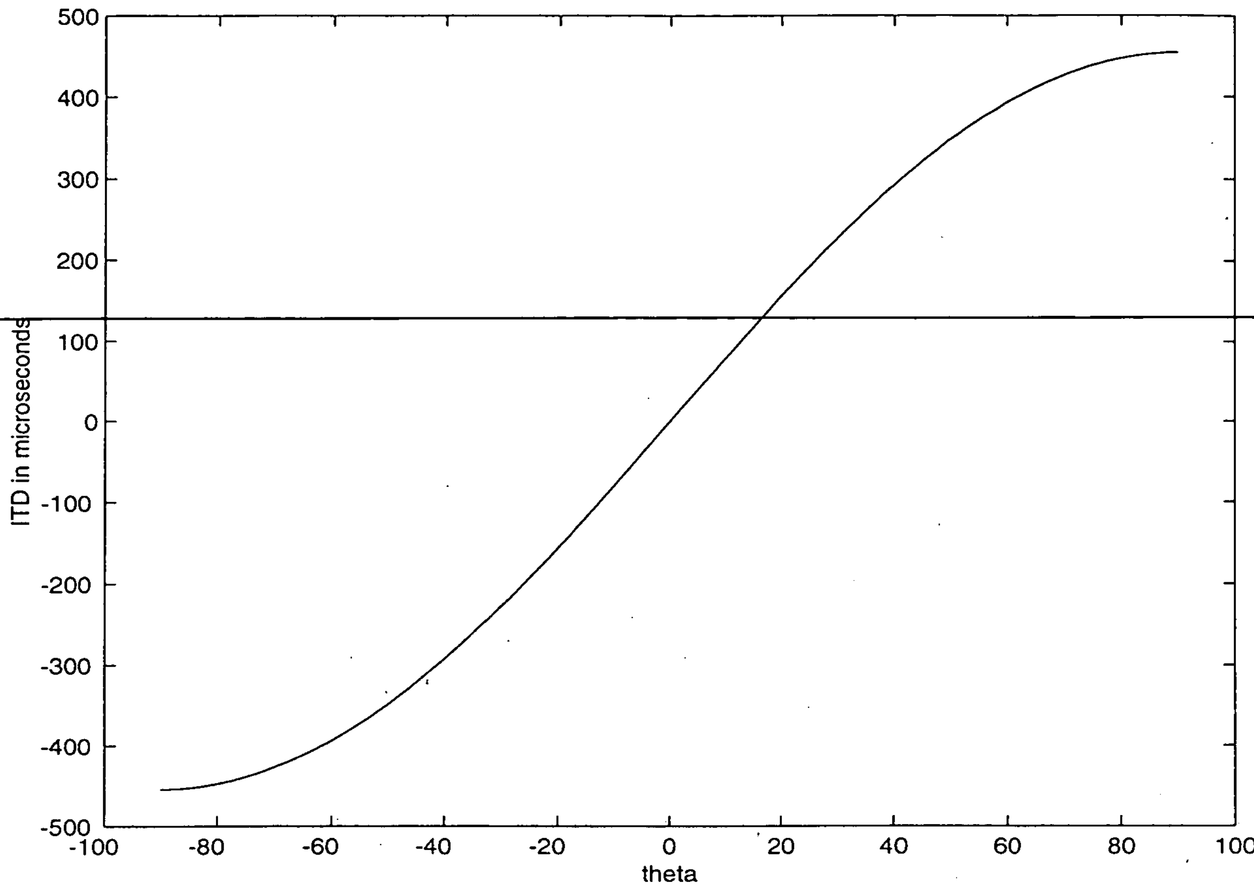
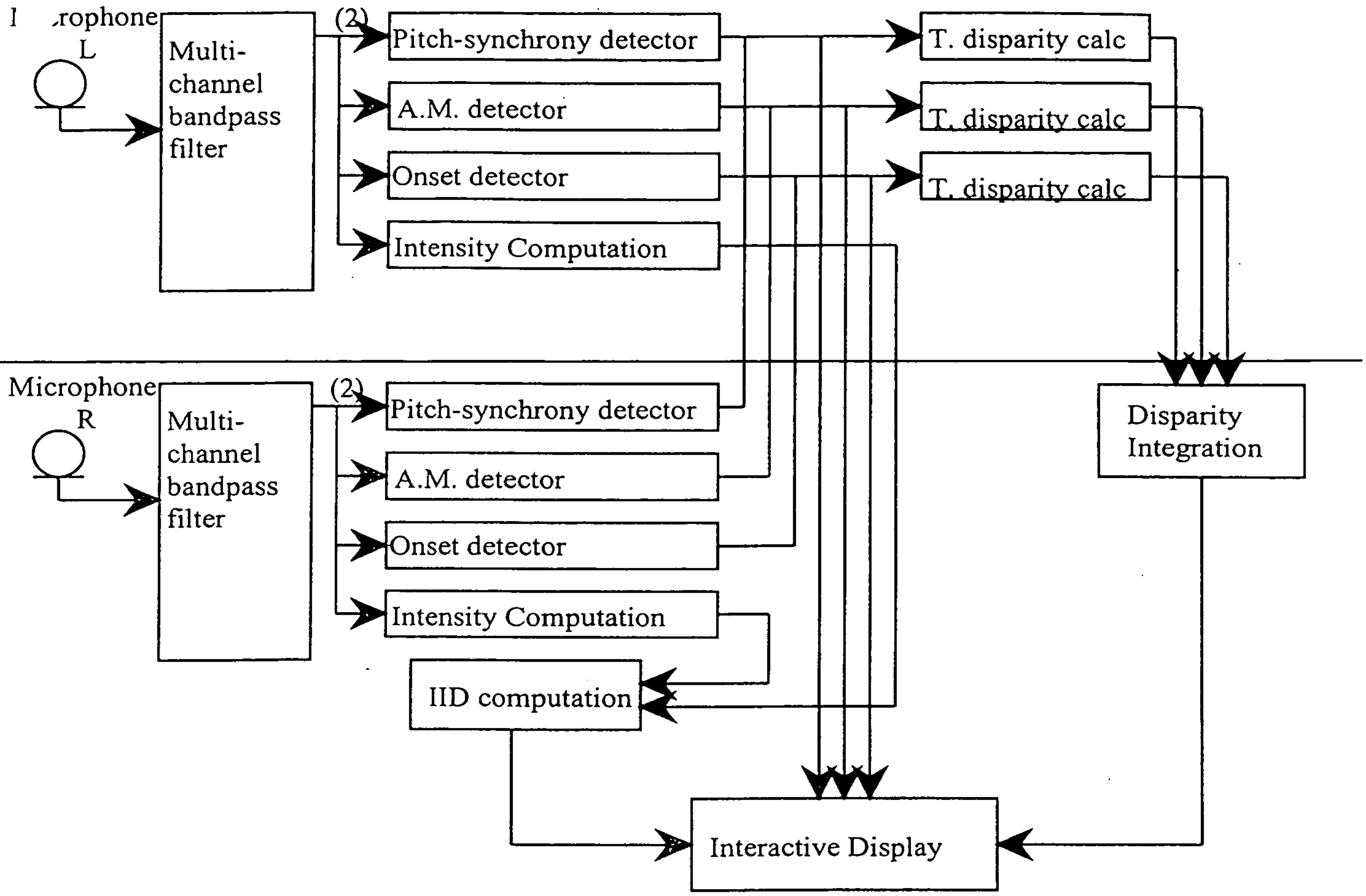

500
400
300
200
100
0
-100
-200
-300
-400
-500
ITD in microseconds
-100
-80
-60
-40
-20
0
20
40
60
80
100
theta

Figure 1.



I ,rophone
L
Multi-
channel
bandpass
filter
(2)
Pitch-synchrony detector
A.M. detector
Onset detector
Intensity Computation
T. disparity calc
T. disparity calc
T. disparity calc
Microphone
R
Multi-
channel
bandpass
filter
(2)
Pitch-synchrony detector
A.M. detector
Onset detector
Intensity Computation
Disparity
Integration
IID computation
Interactive Display

Figure 2.

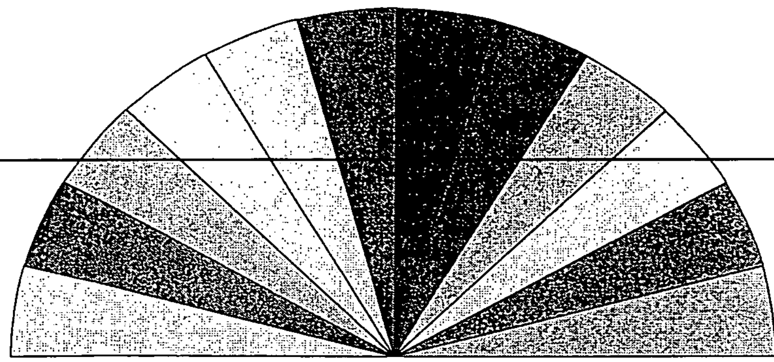


Figure 3.

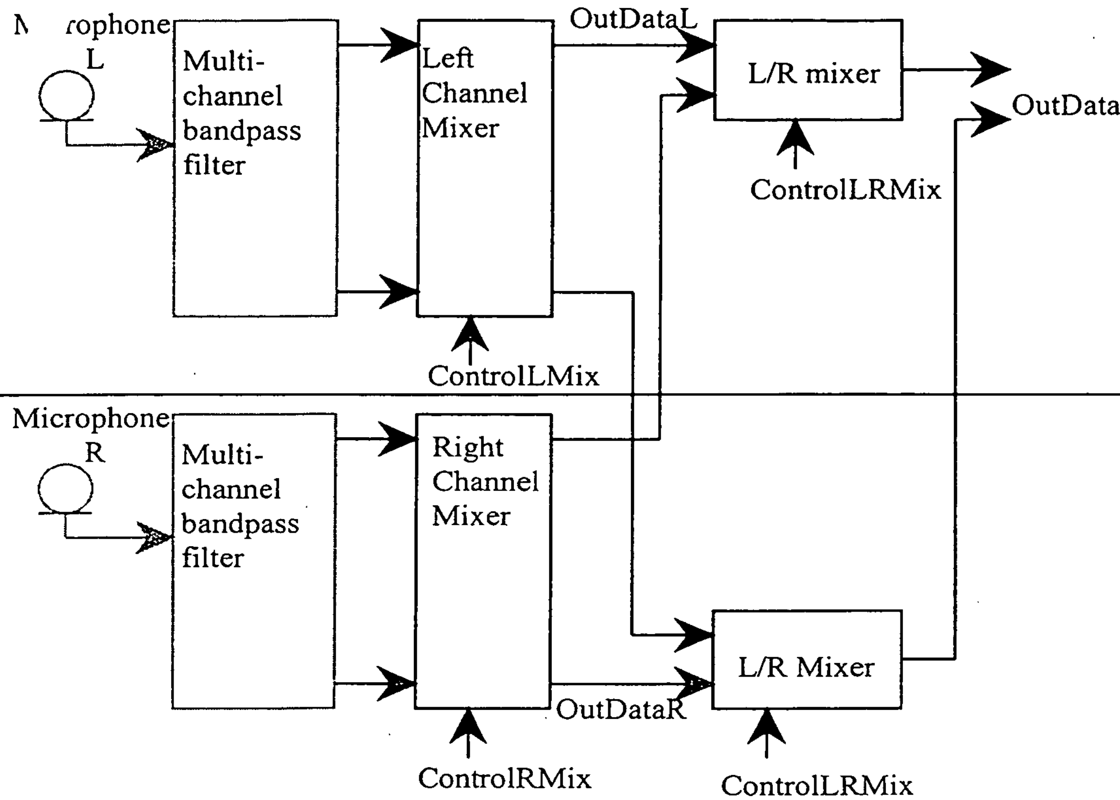

Microphone
L
Multi-
channel
bandpass
filter
Left
Channel
Mixer
OutDataL
L/R mixer
OutData
ControlLRMix
ControlLMix
Microphone
R
Multi-
channel
bandpass
filter
Right
Channel
Mixer
L/R Mixer
OutDataR
ControlRMix
ControlLRMix

Figure 4

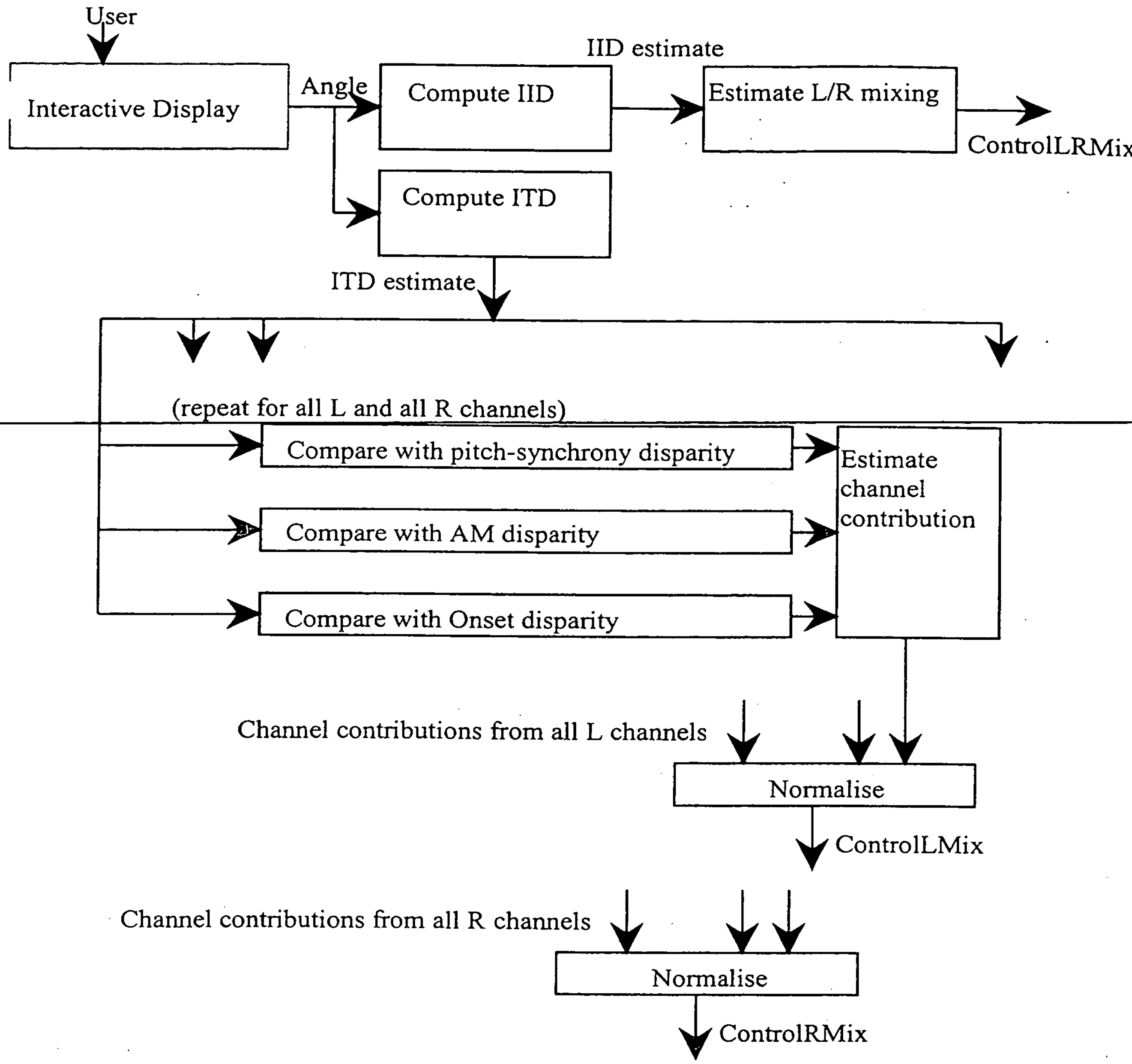

User
Interactive Display
Angle
Compute IID
IID estimate
Estimate L/R mixing
ControlLRMix
Compute ITD
ITD estimate
(repeat for all L and all R channels)
Compare with pitch-synchrony disparity
Compare with AM disparity
Compare with Onset disparity
Estimate channel contribution
Channel contributions from all L channels
Normalise
ControlLMix
Channel contributions from all R channels
Normalise
ControlRMix

Figure 5.

PCT/GB99/02063

CRUICKSHANK + FAIRWEATHER

30/6/99